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MONTHLY RAINFALL TOTALS REPRESENTING THE EAST MIDLANDS FOR THE YEARS 1726 TO 1975

By J. M. CRADDOCK (University of East Anglia) and B. G. WALES-SMITH (Meteorological Office)

SUMMARY

The problems of producing a homogeneous record of monthly rainfall totals for a limited geographical region, extending from the earliest years of observations up to the present time, are discussed with reference to an area in the East Midlands centred at Pode Hole, near Spalding. Estimates are made of the standard of reliability to be expected from the early data, and monthly totals are given for each of the years 1726 to 1975.

1. INTRODUCTION

This paper sets out to extend the time base of observations suitable for use in the study of regional rainfall. It is intended to be one of several following the same pattern, each of which suggests monthly rainfall totals for a particular region of the British Isles for as long a period of years as the data will support. The East Midlands is the region first considered because four stations in this region, namely Southwick (Oundle), Lyndon, South Kyme and Pode Hole, provide actual observations for all except two of the years 1726 until now. The figures are the best which can be offered at present without embodying corrections which are speculative at this stage, or which depend much on data from stations at a considerable distance. If improvements in statistical method make it clear from observations at distant stations or otherwise that revision is necessary, then the present values can readily be adjusted to include the new evidence.

2. THE 10 YEAR BOOKS AND OTHER SOURCES OF EARLY RAINFALL RECORDS

Ever since G. J. Symons began to collect rainfall records in the 1860s the '10 year books', now kept by the Meteorological Office, have formed the most comprehensive source of information on monthly rainfall in the British Isles. However, as they comprise about 16 000 separate records of which some 6000 are still continuing and total perhaps 250 000 station-years of observations, it is

not always easy to find an individual record when wanted or to estimate the coverage in space and time for a particular area. Hence our first step in seeking to extend recent records back into past centuries was to go through the early volumes of the 10 year books, and to catalogue all records with data for years before 1820. There are about 260 of these for stations in Great Britain, and Table I lists all those for which at least 10 years' annual totals are given or which are important for other reasons. This attempt to provide comprehensive and easy reference to the earliest rainfall records seems to be the first of its kind since one was published by G. J. Symons in 1866 and Table I points to much the most important part of the instrumental evidence on British rainfall in the 1700s which will ever be known. It is included firstly to draw attention to the gaps which exist in the records for particular regions, and secondly to invite any reader who knows of other considerable records for the same period to inform either one of the authors or the Meteorological Office. For the years after 1820 the problem changes from one of finding records of any kind to that of making the best possible use of records known to exist.

Most of the records in the 10 year books before 1820 were known to G. J. Symons and, indeed, appear to have been copied by him, or on his behalf, from the original sources. These are manuscript copies, in copperplate handwriting, on paper of the type used in ledgers. The entries, which include both monthly and annual totals, have been checked for internal consistency. The entries made in Symons's time have been added to at intervals ever since, but there is rarely anything to show the date of any addition or correction, or the name of the person who made it. There is some duplication, since sometimes the same record has been copied twice, by different people working from different source documents, and occasionally it is doubtful which version is to be preferred. Most entries contain some references back to the original sources, and brief notes, also dating back to Symons, on the exposures and construction of the rain-gauges. However, comparisons between these notes and the source documents, in the *Philosophical Transactions of the Royal Society* (1740) for example, show that the figures have been copied with more care than the descriptive notes. The user who works from the 10 year books alone, without reference to the original sources, is liable to lose information recorded in the sources which has never found its way into the Meteorological Office archives.

3. ERRORS IN RAINFALL MEASUREMENTS WHICH MAY BE FOUND IN ANCIENT RECORDS

Table I contains, for each station listed, a comparison between the annual rainfall as reported, averaged over all the years given before 1820, and the estimated 1916–50 average rainfall for the same position, based on the best official maps. It is clear that about half the pre-1820 averages fall below the modern estimates by amounts which cannot possibly be due to climatic change but must be due to defects in the construction or exposures of the ancient instruments. It is therefore useful at this stage to consider the probable nature of these errors.

An extensive bibliography on the measurement of rainfall has been given by Kurtyka (1953). A modern hydrometeorologist inspecting a rainfall station should look for any of nearly 20 sources of error each of which is known to have occurred at least once and which may make the catch as recorded either larger or smaller than it should be. However, most are irrelevant in the present context because of the impossibility of checking the presence of minor faults in

ancient instruments which have long since disappeared. Nevertheless some broad generalizations are justified and useful.

(i) The early observers were mostly scientists, doctors, parsons and country gentlemen who took their scientific activities seriously and who appear to have had the time to treat rain-gauging as a matter of considerable importance. There are no good reasons for believing that they were more prone to making clerical or measuring errors than are the best modern observers. Their letters, preserved for example in the Library of the Royal Society, provide ample evidence of the care they gave to overcoming the instrumental problems of which they knew.

(ii) Of faults leading to an excessive catch, the most important are obvious matters, such as a gauge with a broad brim from which raindrops slide or bounce into the funnel, or a tree overhanging the gauge and dripping into it. It is reasonable to suppose that observers of the calibre of the early pioneers in rain-gauging would not overlook such faults for long.

(iii) Faults leading to a deficiency of catch are the most numerous, and while some are obvious and were avoided from very early years, others are not obvious, or may develop gradually over the years. The modern attitude towards rainfall measurement did not exist in the early 1700s and it is worth while considering the guidance which a prospective observer in those days would have obtained from his predecessors.

The first observer whose records are known is Richard Townley (1694) who gives a graphic description of his rain-gauge. It consisted of a funnel 12 inches in diameter raised above the roof of his country house in Lancashire, with a pipe leading down from it 27 feet vertically before turning in through a window into a container. William Derham (1697) used something similar, since he refers the reader to Townley's article for a description of his apparatus, while Dr James Jurin (1722), although he does not say so at the time, in fact refers to the Royal Society rain-gauge which was on a flat leaded roof. Jurin, as Secretary to the Royal Society, issued an invitation to collaborators to make weather observations according to a common pattern which inspired the pre-1800 observations used here, and most other observers of the early 18th century. He describes the recommended apparatus in detail, and the account of the rain-gauge, translated from his Latin by Miss V. Craddock, is worth quoting:

'Sixth and last, was measured the depth of rainfall, (or snow melted to water) which had fallen since the time before, both in London inches and their decimal parts. Thus I estimated easily that with the help of funnels two or three feet across, water flowing down the funnels could be caught in a container and a cylindrical measure with a scale in inches and decimals. The funnel was so sited that, from wherever the wind blew, no part of the rain might be intercepted either by an intervening building or any other shelter anywhere. Thus there would be a bottle containing water properly closed in from all sides, lest it should disperse into the air, with one narrow opening left to collect the water from above, through the funnel. The diameter of the cylindrical measure should be allotted smaller than that of the funnel by ten parts; thus it is that water is an inch high in the measure to the height of 1/100 inch in the funnel, and thus the fall on the rest of the earth can be calculated, and similarly for the tenth part of inches.'

This, then, is the advice that prospective rainfall observers would have received in the 1720s if they had consulted the main scientific journal of the

TABLE I—IMPORTANT RAINFALL RECORDS FOR YEARS BEFORE 1820

(taken from the Meteorological Office 10 year books in July 1974)

Ref.	Name and Author	Period	Est.	Obs.
			*inches**	
Y2	Tottenham, London (Luke Howard)	1797–1810	25·30	24·36
Y3	Somerset House, London (Royal Society)	1787–1809 1812–1819	23·70	16·22
Y6	Temple Bar, London (William Bent)	1795–1808	23·65	18·62
Y7	Crane Court, London (Royal Society)	1725–1735	23·60	21·73
Y8	Lambeth, London (Symons's MS)	1765–1782	23·40	24·90
Y9	South Lambeth, London	1782–1791	23·74	22·94
Y12	Camden Town, nr London (James Joyce)	1802–1808	25·00	30·73
Y13	Highgate Hill, London (James Joyce)	1809–1815	26·50	32·79
Y18	Falkham, North Fleet } Kent (John Hooker)	1729–1734	(3)	21·57
Y18a	Tonbridge, Kent (John Hooker)	1735–1764	28·80	26·91
Y23	Selborne, Hants (Gilbert White)	1780–1792	38·00	36·41
Y31	Southwick, nr Oundle (George Lynn)	1726–1739	23·80	22·83
Y45	Longleat, Wilts. (Jeremiah Cruse)	1789–1799	35·50	24·75
Y47	Upminster, Essex (Dr W. Derham)	1697–1716	22·00	19·90
Y48	Norwich, Norfolk (W. Anderson)	1750–1762	26·80	25·41
Y49	Plymouth, Devon (Dr J. Huxham)	1725–1752	39·00	30·32
Y59	Stroud, Gloucester (Dr Hughes)	1771–1773 1775–1813	34·00	30·90
Y60	Radcliffe Observatory, Oxford	1795–1804 1815–1819	25·10	21·15
Y64	Lyndon, Rutland (Thomas Barker)	1737–1798 1800	24·56	22·97
Y65	Ferriby, Hull (Editor, Monthly Mag.)	1800–1812	25·00	27·53
Y71	Chatsworth, Derbys. (Lord George Cavendish)	1761–1813	34·00	30·90
Y73	Derby (Mr Swanwick)	1809–1819	28·00	25·06
Y77	Liverpool Docks (Mr Hutchinson)	1775–1792	33·50	34·36
Y78	Liverpool, Walton (Mr J. Holt)	1792–1804	35·00	33·15
Y80	Manchester (Thomas Hanson)	1807–1813 1816–1819	(4)	35·09
Y81	Manchester (Dr Dalton)	1794–1819	(5)	32·63
Y87	Townley, nr Burnley, Lancs. (R. Townley)	1677–1703 with gaps	47·50	41·87
Y88	Lancaster (Dr Campbell)	1784–1796	39·50	44·29
Y91	Kendal (J. Gough) (6)	1788–1799	57·50	59·77
Y96	Barrowby, Leeds (George Lloyd)	1772–1781	27·90	27·14
Y118	Carlisle, Abbey St (Dr J. Carlyle)	1757–1783	32·30	24·33
Y120	Carlisle, Shaddongate (Mr Pitt)	1801–1819	32·30	29·52
Y126	Wigton, Aikbank (Rev. J. Golding)	1790–1810	34·00	34·64
Y131	Dumfries (Dr Copland)	1775–1783 1790, 1793	43·00	38·06
Y133	Branxholm, Roxburgh	1773–1783	34·50	32·07
Y136	London	1798–1809	23·78	22·86
Y147	South Kyme, Lincs. (Rev. H. S. Neucatre)	1800–1819	23·62	25·34
Y151	Welbeck Abbey, Notts. (Duke of Portland's estates)	1807–1819	23·20	25·48
Y157	Kendal (a brother of J. Dalton) (6)	1798–1809	57·50	49·67
Y186	Lancaster, Ellel (Ford)	1798–1817	49·00	38·14
Y194	Kendal (Harrison and Gough) (6)	1810–1819	57·50	50·19

Notes

(1) The estimates are based on the fullest information for 1916–50.
(2) The Obs. column gives the average of annual totals observed and reported for all years before 1819.
(3) Falkham 1728–30 26·70. North Fleet 1731–33 23·00.
(4) 1807–11 35·50. 1812–19 35·00.
(5) 1794–1803 34·00. 1803–1819 34·50.
(6) Sites unknown—taken as modern town of Kendal.

* Non-metric units are used throughout this paper to maintain uniformity with those units used with historical references and quotations.

times. Following Jurin's advice, they would have had rain-gauges which were not sheltered in any direction by obstacles, and which preserved the catch from evaporation, but the funnel might have been so flat that raindrops were scoured out by the wind, and there was then no suggestion that the elevation of the funnel above the ground surface could have had any effect on the catch. Dr Heberden (1767) was the first to demonstrate, by placing similar rain-gauges on the square tower of Westminster Abbey and at his house in Westminster, the general principle that 'the higher the rim of the collecting funnel above the ground surface, the smaller the catch'. This has often been confirmed since, for example, by comparative measurements at Oxford and Paris but the processes involved were not understood till the time of Symons (1881) and Mill (1901). Mill's work in particular shows that the loss of catch with an elevated gauge depends mainly on eddies produced by the horizontal component of the wind, with the result that the loss of catch tends to be greater in the winter months when the winds are on average stronger. Painter (1975) compared measurements from ground level to 45 cm. Nash (1918) analysed the monthly totals from 1871 to 1910 of rainfall measured at Greenwich with gauges at ground level, and 10, 22, 38 and 50 feet above and showed that the average catch of the 38 foot gauge varied from 87 per cent of the ground-level value in August to only 71 per cent in March. Two points should be made to conclude this discussion:

(i) with a sharp-rimmed gauge, reasonably well exposed, it is almost impossible to catch too much rain, so that the general rule can be 'when in doubt, accept the larger reading' and

(ii) when an old record was set up by a gentleman with scientific interests, under what seemed to him to be satisfactory conditions, any changes which took place with time were liable to have produced a gradual diminution of catch. These changes may have included the growth of trees near the gauge, leaks, the slow blockage of the pipe leading to the receiving vessel, or the internal surface becoming porous. Such changes may not have been noticed unless the observer compared his records with a neighbour, but then, if he was not too old to take action, he may have put things right.

4. Stations in the East Midlands

Coming from the general to the particular, the stations considered in this paper are listed in Table II. The names underlined provide nearly all the data in the homogeneous series produced here; on 12 and 13 May 1976, one of us (J. M. Craddock) visited these sites in search of further evidence. The findings form the basis of paragraph 10. Pode Hole was chosen as key-site, because it has a very good continuing record which started as early as 1829, and is about equidistant from South Kyme and Boston in one direction, and Southwick and Lyndon in the other. Although the distances to the supporting stations ranging from 18 to 22 miles are not negligible, they are across flat country, and are a good deal less than the distances which have to be considered when data for other parts of the country are homogenized, or which must be accepted when a user of such data treats the record for a key-site as referring to his own area.

5. Estimating the conversion factors to be applied to early data

The method of homogenization consists in using the monthly totals given in an early record to estimate totals for the same months at Pode Hole by multiplying

TABLE II—STATIONS USED IN ESTIMATING RAINFALL TOTALS TO REPRESENT THE EAST MIDLANDS FOR THE YEARS 1726 TO 1975

Station	Nat. Grid. Ref.	Altitude	Observer	Period	Distance from Pode Hole	1916–50 estimate
Pode Hole	214219	22′	Various	1829–1975	0	23·65 in
Southwick (Oundle)	920020	110′	George Lynn	1726–1740	22 miles	23·80 in
Lyndon (Rutland)	044907	300′	Thomas Barker	1737–1798, 1800	22 miles	24·56 in
South Kyme (nr Sleaford)	170498	11′	Rev. H. S. Neucatre	1800–1868 except 1826	18 miles	23·62 in
Boston, Grand Sluice	440327	40′	W. Veall *et alii*	1824–1869 1865–1970+	16 miles	24·30 in
Empingham	950086	175′	W. Fancourt	1836–1861	18 miles	24·20 in
Witham-on-the-Hill	165050	170′	General A. C. Johnson	1831–1869	11 miles	23·40 in
Wellingborough	894675	187′	Various	1860–1975	38 miles	24·50 in

by a conversion factor which is itself the product of an exposure factor and a distance factor. The exposure factor converts the observed totals into estimates for a standard rain-gauge well sited at the same place with rim 1 ft above ground. These are based on the consideration of the sites given below. The distance factors convert the estimates for the 1 ft level gauges at different places into estimates for Pode Hole, by taking account of the ratio of the annual catches in the 1916–50 period, as estimated from the latest official maps and given in Table II. These factors and their products are given in Table III.

TABLE III—CONVERSION FACTORS USED FOR THE HOMOGENEOUS PODE HOLE SERIES FOR 1726 TO 1975

Years used	Station	Exposure factor	Distance factor	Product
1726–1736	Southwick	1·030	0·994	1·024
1737–1798	Lyndon	1·080	0·963	1·040
1799	West Bridgford	—	—	1·000
1800–1825	South Kyme	1·030	1·000	1·030
1826	Witham	1·000	1·011	1·011
1827, 1828	South Kyme	1·030	1·000	1·030
1829–1975	Pode Hole	—	—	1·000

6. THE INDIVIDUAL RECORDS

The records for West Bridgford and Witham, each used to estimate for only one year, do not warrant individual discussion, but those for Southwick, Lyndon and South Kyme are more important. The records at Southwick and Lyndon provide the best evidence which still exists for British rainfall regimes before 1800, and deserve further study which may, of course, modify the present conclusions.

(i) Southwick Hall, Oundle has been a gentleman's residence since the Middle Ages, and when the rainfall measurements were made by George Lynn the elder (1740), from 1726 to 1740, the main structure was much the same as it is today. The house is surrounded by lawns, gardens and trees, with the church and village of Southwick at no great distance, and the probability is that these

also have only changed in detail during the last 250 years. George Lynn, in a letter to Dr Jurin, describes the situation of his thermometer and barometer in considerable detail, but says nothing whatever about the exposure of his rain-gauge, an omission which suggests that he considered it too obvious a matter to deserve mention. A modern hydrometeorologist looking for a site for a rain-gauge would indeed have an obvious first choice, namely, the middle of the lawn to the west of the house, in clear view from the windows of the main drawing room (improved by George Lynn). He might also feel that this site, although the best available, is somewhat oversheltered. It lies between the manor house and the church, and there are and probably always have been big isolated trees (although not the same ones) and woods around. Any other site likely to be chosen would be more sheltered, and of course George Lynn had to make his choice without the experience available to modern observers. The impression left by a visit to the site is that an upward revision of the figures by three per cent to allow for exposure is unlikely to be excessive.

(ii) As regards the even more important Lyndon record, Thomas Barker (1771) describes his rain-gauge as follows:

'I have, on the other side, sent, as you desired, the height of my rain measurer above the ground, which, if you think proper, may be added to my former letter. Mr Edward Lawrence, who observed the rain at Stamford part of the time I have done here, generally found more water in his measurer which stood on the ground, than I did in mine; but I cannot depend on his observations, because I have been told the servants at the house used to play him tricks, and pour into his cistern more water than fell in, to which a thing on the ground is very liable . . . My rain cistern has all along stood on the top of a wall, where another meets it at right angles. The top of the cistern on the North side is 7 ft. 3 ins.; on the southwest side 8 ft. 6 ins.; and on the south-east side 10 ft. above the ground; it is all open southward for 25 yards, the north side is an orchard, but no tree hangs over it.'

The immediate response to this account is that a rain-gauge exposed in this way would catch less than one on the ground without any assistance from the pranks of mischievous servants. However, arriving at the right correction is less easy, since none of the experimenters seem to have considered a rain-gauge situated above the junction of two walls. The terrain at Lyndon is more similar to that at Stratfield Turgis than it is to the moors at Rotherham, or the urban terrain around Greenwich, and an exposure factor of 1·080 (which gives a product with the distance factor of 1·040), seems as good as any which can be suggested.

(iii) Information about the record at South Kyme can be pieced together from notes in the 10 year books, where the rainfall totals were copied by G. J. Symons, and an extensive extract from the observation book. During the 1930s a Flt Lt Lowe, stationed at Cranfield, lent the book to the Meteorological Office, stating his intention of depositing it in 'the local museum'. This book contained the observations of pressure, temperature and rainfall made by the Reverend H. S. Neucatre, vicar of Kyme Manor, from his appointment in 1826 until the summer of 1869, but it also contains similar observations for the years 1800 to 1825, which Neucatre must have copied from an at present unknown source. The site of the rain-gauge is stated to be 'near the old tower'. The book was returned to Flt Lt Lowe, and has not been seen since. A visit to South Kyme showed that the old tower is not the remains of a previous church, but a most

impressive relic from a former castle, standing in open parkland not far from the church and manor house, which was built of stone from the castle. A water-colour of the old tower in the Museum of Local Antiquities at Lincoln shows that the surroundings of the old tower when the picture was painted (between 1850 and 1870) were the same as they are now, and it is hard to see how a rain-gauge could be sited near the old tower and avoid overexposure, without placing it in the actual shelter of the tower. Here again, an upward revision of the observations of three per cent to allow for exposure seems reasonable.

(iv) As regards Pode Hole itself, the facts are summarized in the official records as in Table IV.

These changes in gauge height etc. should not result in serious inaccuracies, and it appears, too, that some of them may be matters of description rather than fact, since it seems that for many years a Glaisher gauge, with rim 2 ft 6 in above the ground surface, was surrounded by a low hedge of 1 ft 3 in height. These observations have therefore been accepted as correct.

TABLE IV—INFORMATION ABOUT PODE HOLE

Spalding (Pode Hole) NGR TF(53)214219 12 ft a.s.l. Gauge No. 32-154720
Brief history of rain-gauging

Year	Observer/Authority	Gauge dia.	Height of rim	Site a.s.l.	Information	Notes
1829	A. Harrison		0′ 00″	19′ ?	10 yr	
1869	A. Harrison		0′ 00″	19′	10 yr	
1870	A. Harrison	12″	0′ 00″	20′ ?	BR	
1872	A. Harrison	12″	0′ 03″	20′	BR	
1890	A. Harrison	12″	0′ 03″	20′	BR	
1891	W. Grigg	12″	1′ 00″	20′	BR	
1905	W. Grigg	12″	1′ 00″	20′	BR	1905 may have been Rly Stn record (10 yr)
1906	W. Grigg	N & Z Glaisher	1′ 00″	20′	10 yr	
1910	W. Grigg	N & Z Glaisher	1′ 00″	20′	10 yr	1906–10 data rec'd 23.5.1912
1911	H. Bain	8″	1′ 03″	13′	BR	
1938	H. Bain	8″	1′ 03″	13′	BR	
1939	Deeping Fen Drainage Trust	8″	1′ 03″	12′	BR	
1946	Deeping Fen Drainage Trust	8″	1′ 03″	12′	BR	
1947	South Holland Drainage Board	8″	1′ 03″	12′	BR	
1958	South Holland Drainage Board	8″	1′ 03″	12′	BR	10 yr gives gauge as Glaisher 1951–60
1961	Deeping Fen, Spalding and Pinchbeck Internal Drainage Board	8″ Glaisher	1′ 03″	12′	10 yr	
1965	Deeping Fen, Spalding and Pinchbeck Internal Drainage Board	8″ Glaisher	1′ 03″	12′	10 yr	

(1962) (Two 5″ gauges installed—Pode Hole 2 and 3) 10 yr

N & Z = Negretti and Zambra BR = British Rainfall 10 yr = 10 year book

7. DISCUSSION AND CONCLUSION

The annual totals which result from this homogenization are given as percentages of the 1916–50 annual average in Table V which follows, and the monthly totals

TABLE V—ESTIMATED ANNUAL RAINFALL TOTALS FOR 1726–1828 AND MEASURED TOTALS FOR 1829–1975 FOR PODE HOLE EXPRESSED AS PERCENTAGES OF THE 1916–50 AVERAGE 23·65 in (600·7 mm)

1726	115·1	1754	87·3	1782	141·1	1810	123·9	1838	89·2	1866	113·1	1894	94·7	1922	111·2	1950	101·9
1727	108·0	1755	93·4	1783	100·2	1811	109·0	1839	133·8	1867	98·8	1895	92·5	1923	96·8	1951	116·1
1728	116·0	1756	110·8	1784	119·7	1812	116·3	1840	90·1	1868	104·7	1896	96·2	1924	111·9	1952	96·1
1729	101·8	1757	104·1	1785	88·9	1813	104·2	1841	124·5	1869	117·8	1897	99·9	1925	97·3	1953	98·3
1730	92·9	1758	94·9	1786	120·0	1814	114·6	1842	135·7	1870	71·3	1898	85·6	1926	99·2	1954	124·3
1731	76·9	1759	92·1	1787	100·2	1815	105·9	1843	124·5	1871	107·9	1899	88·2	1927	124·7	1955	86·8
1732	88·3	1760	80·4	1788	75·6	1816	165·1	1844	93·9	1872	137·4	1900	120·5	1928	106·9	1956	97·5
1733	76·3	1761	94·1	1789	123·1	1817	118·6	1845	115·2	1873	83·0	1901	99·7	1929	88·4	1957	101·3
1734	119·1	1762	78·7	1790	95·1	1818	114·0	1846	110·3	1874	68·7	1902	95·7	1930	105·7	1958	132·7
1735	107·4	1763	126·4	1791	108·7	1819	108·7	1847	108·3	1875	136·4	1903	130·0	1931	109·0	1959	76·0
1736	105·7	1764	103·3	1792	129·3	1820	104·0	1848	145·0	1876	131·0	1904	93·9	1932	107·2	1960	126·7
1737	92·1	1765	87·9	1793	100·8	1821	137·2	1849	116·0	1877	102·5	1905	104·1	1933	80·8	1961	90·8
1738	75·5	1766	83·4	1794	116·9	1822	101·4	1850	88·5	1878	108·4	1906	110·0	1934	78·9	1962	77·5
1739	94·8	1767	93·7	1795	94·1	1823	93·8	1851	94·1	1879	103·1	1907	94·9	1935	100·9	1963	85·1
1740	76·1	1768	135·9	1796	97·1	1824	136·2	1852	131·1	1880	157·0	1908	72·8	1936	109·1	1964	70·9
1741	70·3	1769	94·5	1797	122·5	1825	94·4	1853	112·5	1881	110·4	1909	101·5	1937	126·3	1965	109·8
1742	76·0	1770	125·6	1798	96·4	1826	75·7	1854	75·1	1882	129·0	1910	110·4	1938	83·4	1966	112·1
1743	70·6	1771	77·3	1799	120·3	1827	99·9	1855	93·1	1883	130·6	1911	80·3	1939	119·0	1967	86·3
1744	99·9	1772	126·0	1800	108·0	1828	125·1	1856	95·7	1884	70·9	1912	124·2	1940	94·6	1968	111·3
1745	90·3	1773	129·2	1801	107·0	1829	127·9	1857	117·8	1885	101·0	1913	89·3	1941	130·2	1969	106·1
1746	81·1	1774	155·0	1802	77·5	1830	145·0	1858	74·0	1886	127·9	1914	92·1	1942	93·9	1970	87·8
1747	105·9	1775	139·4	1803	96·2	1831	145·1	1859	106·8	1887	64·0	1915	108·8	1943	79·3	1971	84·7
1748	75·7	1776	122·4	1804	114·7	1832	122·1	1860	128·4	1888	90·9	1916	117·9	1944	101·0	1972	77·0
1749	70·1	1777	103·8	1805	107·4	1833	105·5	1861	108·9	1889	112·1	1917	84·3	1945	85·3	1973	85·5
1750	72·2	1778	115·5	1806	107·6	1834	76·5	1862	105·3	1890	85·3	1918	111·9	1946	115·0	1974	94·1
1751	119·5	1779	96·2	1807	86·1	1835	102·3	1863	96·7	1891	106·3	1919	112·0	1947	79·8	1975	83·5
1752	93·0	1780	88·4	1808	113·8	1836	112·7	1864	74·6	1892	96·2	1920	101·8	1948	97·9		
1753	97·6	1781	91·5	1809	108·5	1837	101·1	1865	123·2	1893	76·7	1921	53·5	1949	84·8		

from 1726 to 1828 are in Table VI (the monthly totals for 1829 to the present are the published figures for Pode Hole). These figures are offered as the best advice now available on the rainfall regimes of the East Midlands during the last 250 years. It would be difficult at present to suggest better data for relation to agricultural statistics in Lincolnshire, for example, but their suitability for use with data for places further afield is less clear. The question of the manner

TABLE VI—MONTHLY AND ANNUAL RAINFALL TOTALS AND DECADAL AVERAGES FOR PODE HOLE 1726–1828 (ESTIMATED) AND 1829–1975 (MEASURED)

	J	F	M	A	M	J	Jy	A	S	O	N	D	Year	Dec.
1726	430	103	154	101	41	409	378	29	528	151	142	255	2721	
1727	322	204	142	129	438	330	202	30	213	156	41	288	2555	
1728	471	95	335	202	147	289	329	98	88	286	156	249	2745	
1729	16	49	134	113	159	85	231	250	545	225	428	172	2407	
1730	41	154	266	82	256	348	205	87	164	307	205	82	2197	
1731	82	102	15	215	31	348	174	164	154	143	154	236	1818	
1732	92	123	143	123	348	61	184	174	72	379	123	266	2088	
1733	102	143	225	102	2	205	225	369	143	61	51	174	1802	
1734	51	266	184	61	522	133	184	410	174	287	92	451	2815	
1735	215	72	225	174	154	246	236	328	328	174	174	215	2541	
1736	236	297	215	61	82	143	614	174	143	266	61	205	2497	
1737	63	173	184	71	104	75	32	655	361	210	59	190	2177	
1738	186	59	124	128	225	252	64	148	219	171	72	137	1785	
1739	253	260	84	269	193	160	204	244	198	54	162	160	2241	
1740	26	6	66	90	108	149	382	291	168	109	155	251	1801	2157
1741	113	64	59	28	46	142	90	170	513	152	204	51	1632	
1742	149	89	5	199	161	149	327	17	185	249	252	17	1799	
1743	43	37	124	130	90	40	544	116	1	321	75	149	1670	
1744	125	98	149	287	131	362	85	100	343	327	236	122	2365	
1745	86	59	264	178	119	359	75	409	94	152	215	128	2138	
1746	183	178	196	79	57	302	150	48	170	236	186	133	1918	
1747	297	126	129	106	294	162	234	7	200	60	512	378	2505	
1748	98	38	203	142	123	316	362	135	57	110	45	161	1790	
1749	258	106	194	57	115	316	109	79	64	113	72	174	1657	
1750	115	93	106	244	103	215	157	67	104	92	220	190	1706	1918
1751	322	96	213	320	276	192	519	164	271	189	139	122	2823	
1752	262	144	125	86	222	320	383	138	50	31	113	326	2202	
1753	176	191	122	146	102	105	269	352	74	152	219	401	2309	
1754	96	93	130	151	146	300	400	110	11	194	204	231	2066	
1755	106	86	173	204	145	188	165	235	265	170	327	147	2211	
1756	210	72	142	406	131	309	333	443	216	159	101	98	2620	
1757	223	61	199	217	142	38	312	630	54	203	156	227	2462	
1758	194	214	186	96	132	225	522	178	152	107	95	145	2246	
1759	92	40	194	315	285	309	97	388	88	156	102	112	2178	
1760	110	194	47	41	93	257	94	171	242	263	223	167	1900	2302
1761	20	153	55	51	211	363	59	375	244	384	150	160	2225	
1762	180	101	159	61	77	79	116	376	159	432	96	24	1860	
1763	62	300	96	72	239	253	589	305	344	167	197	366	2990	
1764	414	118	86	158	114	227	480	184	86	141	184	250	2442	
1765	149	129	288	219	43	82	60	291	73	503	133	109	2079	
1766	17	218	81	204	342	237	245	43	112	86	202	186	1972	
1767	320	208	109	88	220	225	383	158	72	293	97	42	2215	
1768	294	318	41	210	168	470	250	179	315	324	420	224	3213	
1769	125	162	72	87	151	496	207	245	268	125	128	167	2233	
1770	88	77	201	198	161	288	186	236	127	324	813	271	2970	2420

All totals and averages are expressed in hundredths of an inch. 1 inch=25·4 mm.

TABLE VI—*continued*

	J	F	M	A	M	J	Jy	A	S	O	N	D	Year	Dec.
1771	147	97	95	101	69	165	108	222	121	423	82	201	1831	
1772	223	362	244	92	194	405	93	175	469	340	256	128	2981	
1773	118	152	58	62	711	249	112	352	292	272	375	302	3055	
1774	344	203	284	158	327	258	336	407	832	121	159	237	3666	
1775	205	262	180	108	94	93	424	495	590	362	371	113	3297	
1776	261	332	158	93	170	259	192	541	255	214	293	128	2896	
1777	112	251	131	165	206	309	333	134	53	417	164	179	2454	
1778	206	99	125	108	137	282	426	41	173	441	400	294	2732	
1779	22	233	14	197	132	251	420	157	128	184	213	326	2277	
1780	105	163	123	284	125	200	163	45	357	320	152	55	2092	2728
1781	235	173	17	202	101	308	175	114	417	8	329	177	2166	
1782	242	67	200	638	595	135	281	323	536	156	111	54	3338	
1783	188	240	167	58	439	315	277	114	150	69	185	166	2368	
1784	196	128	114	181	301	396	528	292	181	23	248	242	2830	
1785	155	38	22	19	70	163	341	448	344	172	118	212	2102	
1786	361	70	86	130	248	164	187	274	295	495	306	223	2839	
1787	43	89	185	179	163	187	330	205	128	388	152	321	2370	
1788	101	278	111	61	158	63	186	289	253	147	47	93	1787	
1789	270	192	120	105	175	463	443	34	295	513	125	177	2912	
1790	194	25	27	71	303	248	234	180	163	103	327	375	2250	2496
1791	251	132	84	201	119	96	419	303	62	345	440	120	2572	
1792	218	74	114	420	173	420	382	297	414	183	79	283	3057	
1793	199	111	288	312	47	44	81	271	400	132	357	140	2382	
1794	44	146	173	207	108	74	437	300	371	367	412	127	2766	
1795	171	208	218	163	42	291	175	144	6	472	192	144	2226	
1796	203	171	40	68	295	97	587	116	197	137	213	174	2298	
1797	137	8	95	300	263	439	319	252	498	119	168	298	2896	
1798	107	160	55	137	197	99	306	202	292	315	265	146	2281	
1799	169	285	130	292	175	76	259	506	490	221	162	80	2845	
1800	368	49	44	384	145	102	58	146	323	162	508	265	2554	2588
1801	203	65	149	60	202	97	373	193	174	158	503	355	2532	
1802	38	213	65	117	127	204	305	75	100	228	172	190	1834	
1803	244	113	56	239	369	158	64	69	151	75	310	428	2276	
1804	270	228	219	200	141	70	359	300	44	265	528	89	2713	
1805	223	176	138	215	119	344	246	408	170	162	130	208	2539	
1806	295	96	145	64	149	65	510	217	203	89	351	361	2545	
1807	96	127	80	43	264	181	90	138	173	125	399	320	2036	
1808	146	138	51	268	203	150	356	249	346	417	277	89	2690	
1809	507	203	72	379	131	94	261	239	207	44	227	204	2568	
1810	28	137	279	93	147	85	357	321	64	307	612	501	2931	2466
1811	137	161	90	146	243	203	373	267	193	266	250	249	2576	
1812	202	331	262	162	216	259	356	192	48	365	270	90	2753	
1813	59	259	78	216	261	286	357	64	168	511	130	75	2464	
1814	380	65	224	152	149	265	135	271	152	267	291	358	2709	
1815	141	150	272	236	130	206	165	254	187	302	167	295	2505	
1816	242	226	244	212	260	506	476	385	418	359	276	301	3905	
1817	399	173	178	90	352	273	291	270	67	150	169	393	2805	
1818	208	277	374	399	267	98	44	33	348	202	300	147	2697	
1819	236	271	141	268	262	176	161	69	280	188	249	269	2570	
1820	179	135	69	153	272	291	356	182	249	216	161	195	2458	2744

TABLE VI—*continued*

	J	F	M	A	M	J	Jy	[A	S	O	N	D	Year	Dec.
1821	284	64	242	169	207	254	302	253	258	272	473	467	3245	
1822	61	75	131	276	165	137	322	162	164	384	398	125	2400	
1823	228	262	125	171	131	205	265	229	188	296	202	228	2220	
1824	65	228	219	213	375	370	183	250	373	267	355	323	3221	
1825	119	90	65	174	337	94	34	260	243	262	296	260	2234	
1826	26	164	137	113	71	47	162	101	524	152	182	113	1792	
1827	149	131	220	111	114	108	182	113	303	470	170	289	2360	
1828	393	108	117	218	176	427	588	322	201	99	109	199	2957	
1829	221	213	28	487	20	412	378	437	345	162	210	112	3025	
1830	325	460	44	275	470	463	320	213	279	63	187	130	3429	2688
1831	200	300	162	230	125	310	499	410	425	290	250	240	3432	
1832	125	10	280	250	310	310	230	425	37	310	350	250	2887	
1833	126	515	206	300	82	312	30	350	120	210	75	170	2496	
1834	225	50	50	100	50	90	625	210	125	100	125	60	1810	
1835	200	175	250	150	220	160	140	120	340	425	180	60	2420	
1836	125	260	325	200	15	270	125	130	230	275	400	310	2665	
1837	360	175	50	170	125	175	210	220	225	220	210	250	2390	
1838	180	175	110	140	170	325	210	200	210	150	140	100	2110	
1839	150	140	370	100	80	500	450	300	225	240	420	190	3165	
1840	200	100	75	75	225	150	330	225	180	190	290	90	2130	2550
1841	375	150	120	120	150	300	300	375	280	300	300	175	2945	
1842	480	150	160	60	275	360	230	290	565	90	450	100	3210	
1843	170	250	125	230	560	180	300	450	25	410	220	25	2945	
1844	150	230	200	25	25	150	370	250	200	250	320	50	2220	
1845	175	75	350	150	270	225	240	480	175	140	120	325	2725	
1846	240	30	40	475	140	60	175	290	310	475	150	225	2610	
1847	140	120	72	75	500	250	50	340	160	380	125	350	2562	
1848	140	325	330	275	50	400	290	380	450	550	60	180	3430	
1849	175	120	75	250	287	237	350	87	387	300	100	375	2743	
1850	163	87	50	137	137	63	475	163	237	237	169	175	2093	2748
1851	187	50	300	150	50	225	525	187	125	213	150	63	2225	
1852	313	63	63	37	87	363	225	537	437	275	525	175	3100	
1853	175	300	163	150	100	300	337	275	137	363	225	137	2662	
1854	265	50	63	75	150	125	163	137	150	187	213	200	1778	
1855	100	225	100	25	213	137	513	113	25	425	225	100	2201	
1856	300	125	37	125	163	125	113	487	150	300	175	163	2263	
1857	413	37	175	225	75	137	187	600	287	413	213	25	2787	
1858	25	63	113	150	137	75	213	250	137	325	113	150	1751	
1859	75	125	113	250	200	200	175	287	325	375	176	225	2526	
1860	265	113	187	75	337	537	125	400	300	187	287	225	3038	2433
1861	100	200	200	87	150	563	450	25	187	137	313	163	2575	
1862	163	63	363	163	237	225	237	213	363	200	113	150	2490	
1863	225	37	100	87	187	387	63	313	265	250	300	75	2289	
1864	75	175	263	113	175	163	63	87	175	137	213	125	1764	
1865	263	213	163	63	225	237	363	487	37	575	187	100	2913	
1866	163	237	113	137	137	400	300	337	363	175	163	150	2675	
1867	400	125	175	175	350	87	175	225	137	200	63	225	2337	
1868	213	137	163	175	50	50	37	375	225	287	113	650	2475	
1869	213	237	287	287	463	163	50	175	287	75	175	375	2787	
1870	137	175	113	75	75	137	87	125	50	287	125	300	1686	2399

TABLE VI—*continued*

	J	F	M	A	M	J	Jy	A	S	O	N	D	Year	Dec.
1871	113	163	113	275	87	350	413	225	475	113	125	100	2552	
1872	275	175	213	300	175	275	350	300	150	400	350	287	3250	
1873	150	137	125	63	225	263	275	225	175	163	125	37	1963	
1874	100	175	63	75	100	63	106	150	237	206	163	187	1625	
1875	213	150	50	87	125	400	900	113	225	387	450	125	3225	
1876	250	213	200	637	75	250	100	137	450	113	237	437	3099	
1877	287	150	137	337	200	87	263	300	175	125	213	150	2424	
1878	150	113	63	150	375	150	37	675	113	187	400	150	2563	
1879	125	187	50	225	313	300	387	263	300	75	113	100	2438	
1880	25	175	87	250	150	550	675	263	587	575	163	213	3713	2685
1881	75	300	163	100	50	175	300	500	187	300	225	237	2612	
1882	150	75	187	250	187	263	275	313	263	500	250	337	3050	
1883	175	287	125	187	225	263	475	75	625	213	325	113	3088	
1884	150	75	87	125	113	63	275	113	225	137	113	200	1676	
1885	125	175	63	137	213	225	25	225	313	463	350	75	2389	
1886	275	13	250	137	413	125	400	250	75	425	275	387	3025	
1887	225	87	63	125	175	63	100	87	175	163	163	87	1513	
1888	69	206	200	225	75	200	450	200	113	13	237	163	2151	
1889	150	150	200	263	550	37	275	275	225	300	63	163	2651	
1890	187	113	267	87	225	225	225	163	25	87	363	50	2017	2417
1891	150	0	125	125	263	137	250	350	113	463	250	287	2513	
1892	125	225	113	113	213	237	237	200	225	400	100	87	2275	
1893	175	225	37	13	100	125	300	100	125	213	250	150	1813	
1894	163	137	50	125	150	225	400	163	125	263	275	163	2239	
1895	263	63	200	175	75	213	250	200	63	237	300	150	2189	
1896	100	75	200	87	75	200	113	137	475	363	125	325	2275	
1897	137	313	213	137	87	225	213	350	313	125	125	125	2363	
1898	100	50	150	225	275	113	87	337	37	275	200	175	2024	
1899	237	125	50	200	250	87	150	150	300	213	137	187	2086	
1900	337	525	63	100	175	225	87	487	37	213	213	387	2849	2263
1901	100	125	150	175	100	125	475	200	100	175	175	437	2337	
1902	87	150	125	150	313	313	137	287	175	200	163	163	2263	
1903	187	75	275	200	275	150	250	450	312	625	175	100	3074	
1904	200	275	225	83	263	50	237	325	200	87	100	175	2220	
1905	125	75	187	200	87	375	275	313	275	137	313	100	2462	
1906	313	200	225	75	163	263	75	275	125	375	313	200	2602	
1907	100	125	125	200	275	150	174	269	77	283	208	259	2245	
1908	59	104	196	214	131	114	229	195	172	100	82	126	1722	
1909	55	18	305	114	105	345	338	189	180	339	42	370	2400	
1910	166	238	72	222	280	107	250	304	122	142	212	497	2612	2394
1911	124	77	148	88	51	210	24	140	170	202	237	421	1898	
1912	280	115	198	16	223	302	498	555	108	175	219	249	2938	
1913	240	57	291	209	182	156	82	153	152	300	238	51	2111	
1914	145	82	258	99	120	302	125	153	62	194	219	419	2178	
1915	202	207	144	51	175	77	492	345	87	128	260	406	2574	
1916	86	354	397	91	191	256	200	342	135	169	294	274	2789	
1917	215	71	112	137	113	179	120	429	105	322	105	86	1994	
1918	224	125	60	167	301	55	296	277	453	184	259	245	2646	
1919	312	258	304	239	51	104	287	243	168	145	204	334	2649	
1920	176	78	223	373	198	237	314	107	231	176	69	226	2408	2415

TABLE VI—*continued*

	J	F	M	A	M	J	Jy	A	S	O	N	D	Year	Dec.
1921	185	53	73	113	116	45	44	197	67	132	115	126	1266	
1922	275	264	183	257	114	84	547	196	199	134	117	261	2631	
1923	142	328	193	116	113	57	215	213	211	266	159	276	2289	
1924	222	93	60	152	374	204	295	198	190	465	234	210	2647	
1925	104	195	118	182	311	12	177	244	270	261	209	217	2300	
1926	315	154	36	209	259	288	132	89	249	220	315	81	2347	
1927	161	211	229	171	110	342	221	296	412	217	304	275	2949	
1928	285	106	175	103	151	408	224	206	47	341	261	222	2529	
1929	166	97	19	90	106	122	194	138	81	259	391	427	2090	
1930	213	62	164	233	265	54	295	233	389	104	284	205	2501	2355
1931	217	269	40	227	236	157	408	263	406	71	199	84	2577	
1932	81	88	174	264	377	57	409	284	320	279	139	63	2535	
1933	125	233	226	114	143	162	70	56	243	281	194	63	1910	
1934	134	76	141	206	54	104	191	204	117	93	206	341	1867	
1935	216	171	47	255	59	244	60	158	264	250	400	263	2387	
1936	303	222	96	204	151	355	507	84	150	144	210	155	2581	
1937	320	291	315	260	475	154	330	41	159	217	157	267	2986	
1938	236	130	27	17	210	99	215	132	189	154	161	403	1973	
1939	458	64	181	230	78	169	314	249	135	425	300	211	2814	
1940	207	251	165	101	90	79	361	49	62	266	457	150	2238	2387
1941	378	252	358	93	294	73	563	394	94	218	307	55	3079	
1942	238	143	135	75	252	93	223	252	148	228	285	150	2222	
1943	383	28	57	107	205	229	99	237	193	108	155	74	1875	
1944	164	181	19	183	99	275	224	270	380	226	254	113	2388	
1945	220	164	58	84	149	246	173	321	140	199	63	200	2017	
1946	110	246	107	116	156	223	214	354	219	242	514	218	2719	
1947	186	183	423	192	47	230	208	5	118	21	88	187	1888	
1948	375	91	49	115	267	304	106	228	214	220	144	203	2316	
1949	126	69	85	198	224	52	237	117	130	371	266	131	2006	
1950	85	302	62	218	285	172	268	240	217	67	370	123	2409	2292
1951	250	309	335	223	317	74	123	365	124	102	398	127	2747	
1952	163	44	277	142	307	95	25	265	261	256	249	190	2274	
1953	100	188	87	165	271	343	196	356	110	219	213	77	2325	
1954	169	229	166	27	386	278	261	334	224	235	417	215	2941	
1955	244	304	199	105	302	232	34	88	99	150	136	160	2053	
1956	489	105	87	133	107	245	229	379	147	108	91	187	2307	
1957	110	265	195	29	157	218	264	242	390	106	194	224	2395	
1958	243	331	171	87	240	379	373	427	206	265	145	272	3139	
1959	294	17	266	127	71	58	227	95	34	103	162	344	1798	
1960	366	265	140	46	78	109	273	294	268	458	349	351	2997	2498
1961	253	129	35	277	62	86	194	179	198	228	205	301	2147	
1962	126	54	124	232	116	12	156	282	274	81	238	138	1833	
1963	113	75	267	196	122	158	162	341	131	81	320	48	2014	
1964	79	102	296	192	60	268	88	176	75	96	111	134	1677	
1965	204	77	210	164	119	155	284	205	451	24	298	405	2596	
1966	117	298	39	314	177	326	198	311	185	269	197	219	2650	
1967	66	126	86	219	391	142	123	107	135	303	199	145	2042	
1968	146	75	67	255	194	221	428	325	346	197	247	131	2632	
1969	287	183	256	132	470	172	242	157	26	30	299	255	2509	
1970	213	176	134	277	27	101	160	211	86	73	479	140	2077	2218
1971	268	32	167	143	202	198	114	297	80	146	217	140	2004	
1972	192	111	248	129	157	123	147	50	182	28	234	220	1821	
1973	60	66	61	156	384	352	298	53	233	143	72	143	2021	
1974	150	159	98	29	67	222	213	343	218	362	274	91	2226	
1975	202	76	354	286	235	45	195	84	179	59	132	129	1976	

in which the value of rainfall evidence decreases with distance, both annually and seasonally, is still under investigation. There are other homogeneous series published or in course of preparation, including series from Kew (Wales-Smith 1971)*, Manchester (Manley 1971)* and other places in Great Britain and also several from adjacent continental countries. Comparisons may suggest revision of a series which seems to be getting unreasonably out of line with the rest, or which is at variance with other evidence on the prevailing rainfall regimes; several years may elapse before climatologists can be assured that the homogenized records are as near the truth as the nature of the evidence will allow.

When evaluating and using a carefully constructed 'key-site' assemblage of monthly rainfall estimates made from recorded or intelligently adjusted totals at other places the following points should be borne in mind:

(i) The distribution of severe thunderstorms over a given area in a summer month can easily result in totals differing by as much as 2 inches at places only a few miles apart. Similarly, the distribution of intense rainfall in a major, synoptic-scale rainfall event lasting, say, two or three days can easily result in a 20 per cent difference between annual totals at two places with fairly low average annual rainfalls and only some 50 miles or even less apart.

(ii) At the worst an estimated monthly total for a 'key-site' is a good estimate of the rainfall not far from the site even if not at the site itself. At best the estimate is a close approximation to the true total fall at the site. Summer-month estimates are generally less reliable than those for other seasons. In the authors' view, the figures, with all their uncertainties, present a fairer view of the rainfall regimes of the East Midlands than has been available hitherto, and the references given enable any reader to judge the evidence for himself.

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AGROMETEOROLOGICAL USE OF THE SYNOPTIC DATA BANK IN PLANT DISEASE WARNING SERVICES

By R. J. ADAMS and JUDITH M. SEAGER

Summary

The agricultural section of the Meteorological Office has for some years offered a plant disease data service to the Ministry of Agriculture, Fisheries and Food. Information has been provided on the occurrence of weather conditions conducive to the spread of various plant diseases. In the past this service has been based on the manual extraction of meteorological data from incoming weather reports. An account is given of the conversion of these schemes to automatic extraction from the synoptic data bank of the Meteorological Office COSMOS computer. The form of the disease criteria and the advantages gained from a computerized scheme are described.

Introduction

The rate at which biological processes take place is affected by the weather and this applies not only to the growth and development of a particular plant but also to the diseases affecting it. Diseases which affect agricultural and horticultural crops can cause a reduction in yield which may be considerable in certain years. This means a financial loss both to the individual farmer and to the country as a whole. Sprays can be applied to combat some of the diseases, but applications need to be kept to a minimum because of their high cost, possible mechanical damage to the crop and long-term environmental effects.

Work has been carried out in the past by plant pathologists of the Ministry of Agriculture, Fisheries and Food (MAFF) and agricultural meteorologists to identify weather conditions which are favourable for the development and spread of certain crop diseases. In some cases it has been possible to define criteria for potential infection periods in terms of meteorological variables, quantities which are observed as routine. Other factors will affect the development of disease and these include the growth stage of the crop, existing disease levels and carry-over from previous years.

Plant pathologists, given information about potential infection periods together with a knowledge of these other factors, can advise on the need for spraying and the best timing to achieve optimum effect. It is usually necessary for the spray to be applied within a few days of the occurrence of an infection period, thus the information has to be passed to the plant pathologists with the minimum of delay. Schemes have been in operation (some for several years) whereby weather data for the past 24 hours have been examined, infection periods identified and plant pathologists informed by telephone, telex or letter. The number and efficiency of warning schemes which could be operated using traditional 'manual' methods were limited, thus an automated method was initiated to extend and improve the service. Computer programs have been written (the first became operational in 1975) which extract the required data from the synoptic data bank of the computer at Meterological Office Headquarters. The data are automatically processed to check whether certain criteria have been satisfied. Finally a paper tape containing the required information is produced. This allows telex transmission of the data to MAFF Headquarters and thence to regional plant pathologists.

Diseases for which infection periods have been defined

Apple scab

Apple scab is a fungal disease which causes lesions on the leaves and developing fruit which can become misshapen if heavily infected. The fungus over-winters on fallen leaves and infects the apple trees in the spring when the buds are bursting. The impact of raindrops causes spores to be released from the fallen leaves and then a period of leaf wetness allows the spores to infect the new growth on the tree. The length of the period of leaf wetness required for infection depends on the average temperature throughout the period. A 'Mills period' (Mills and La Plante, 1954) was defined, based on leaf wetness which is not an observed meteorological quantity. Following the development of an instrument for continuously recording the wetness of a polystyrene element (Hirst, 1957), it was found that hours of surface wetness correspond very nearly to hours when the relative humidity is not less than 90 per cent (Hearn, 1961). Although it is recorded, relative humidity is not reported hourly to Bracknell by observing stations. Since dry-bulb and dew-point temperatures are reported rounded to the nearest whole degree Celsius, calculations of relative humidity from these temperatures cannot be precise. A difference between reported dry-bulb and dew-point temperatures of 0°C or 1°C corresponds in most cases to a relative humidity of 90 per cent or more, but occasionally relative humidities in the range 88–90 per cent will be included and some greater than 90 per cent will be missed. Thus the depression of the dew-point may be used as an indicator of leaf wetness and it has been possible to redefine the criteria using only readily available meteorological data from hourly observations. 'Smith periods' have been defined as follows (Preece and Smith, 1961):

A possible infection period starts when precipitation is reported, and continues as long as there is precipitation, or a dew-point depression of 1°C or less is reported. Breaks in these conditions of one hour are allowed. A 'Smith period' occurs when this period satisfies the temperature/time condition as for the 'Mills period'.

In practice this requires that the relative humidity criteria are satisfied for at least nine hours. A 'near miss' condition can also occur, defined as a period which is either one hour too short, or 0·5°C too cool to satisfy the temperature/time criteria.

Barley mildew

Barley mildew is a disease which, if unchecked, can spread very rapidly. It is a fungal disease in which the mildew affects the leaves, reducing their photosynthetic efficiency, producing a loss in grain yield which can be very severe, with annual losses estimated to be about £30–£40 million. These losses can be reduced dramatically by the timely application of suitable sprays.

Spores of barley mildew tend to be released under dry conditions and their spread assisted by strong winds. Two sets of criteria have been defined and are in current use. Polley and Smith (1973) suggested that the following conditions are favourable for spore release:

daily maximum temperature above 15·6°C
daily sunshine more than 5 hours
daily rainfall less than 1 mm
wind speed at 00, 06, 12 or 18 GMT greater than 15 knots.

The number of these conditions occurring determines the 'Polley count' for the day. A high-risk day is a day on which one of the following is satisfied:

a Polley count of 4
the 2nd consecutive day with a count of 3
the 3rd consecutive day with a count of 2 provided that at least one of these days had a count of 3.

An alternative method of identifying high-risk days is by means of the 'Smith index', I, defined as:

$$I = 3T + \tfrac{1}{2}W + H$$

where T = maximum temperature (°C), W = wind speed at 1200 GMT (knots) and H = hours of sunshine for the day in question (Polley and Smith, 1973). A high-risk day is one on which this index exceeds 64.

Plant pathologists can advise on the best time to spray from a knowledge of high-risk periods, current levels of mildew in the crop and growth stage of the crop.

Methods of deriving plant disease data

The criteria outlined in the previous sections were all designed (or subsequently modified) to incorporate data which are reported to the Meteorological Office Headquarters primarily for use in synoptic forecasts in the Central Forecasting Office. These data are automatically stored in the synoptic data bank of the Meteorological Office COSMOS computer complex to be immediately available for forecasting programs.

The barley mildew warning scheme was the first of the agrometeorological services to be automated, the new system being introduced in 1975. In previous years during the period 15 April–31 July relevant data were extracted by hand from copies of the teleprinter messages received from the collecting centres; 35 stations in England and Wales were used and these had to be identified from among all those reporting, as had the individual figures specifying the required elements in the messages. All the data required to calculate the Smith index and Polley count were then tabulated and passed to the Telecommunications Branch for manual punching and transmission to the appropriate recipients. An analyst familiar with meteorological codes and the day-to-day running of the scheme could expect to produce this final table within two to three hours of the last observation. The analyst also had to compute the Smith indices and Polley counts for stations in the south-east region, and inform plant pathologists by telephone if they reached critical values. For other regions, the meteorologists at MAFF Bristol, Cambridge and Harrogate were responsible for these calculations and the information service.

The computer program followed essentially the same series of operations as those involved in the manual operation, but in addition indices and counts for all stations were evaluated and included in the final table. The main problems in programming arose from the different ways in which the same meteorological information is reported by different classes of observing stations. For example, some stations report maximum temperature and a 12 hour rainfall total at 2100 GMT; others report at 0900 GMT on the following day, with a 24 hour rainfall figure. Some stations report sunshine hours in precisely defined positions within the message while others include this information within one of a varying

number of '9-groups'. The program thus has to identify the appropriate group of figures if present and recognize that it refers to sunshine hours and not, for example, to optical phenomena such as rainbows or haloes. A small section of the program deals with the computation of daily rainfall totals involving trace amounts, which are stored as −0·1 mm in the synoptic data bank. The program also has to cope with occasions of missing and, to some extent, misreported data. For example, the absence of sunshine hours from the calculation of the Smith index would give an erroneous result, but the failure to include an observation of a 1200 GMT wind would not matter in the calculation of a Polley count if (and only if) a report at one of the other observing times exceeded 15 knots.

The program produces a table of meteorological data, indices and counts in a computer printout format. To eliminate the need for manual punching of the table by telecommunications staff a further section was written to provide a simultaneous output of the table on paper tape, in the particular form required for teleprinter transmission. This message is then passed by telex to MAFF Headquarters for insertion in their telecommunications network for transmission to the regional meteorologists and plant pathologists. The total computing time to extract and process the data and to prepare the tape for transmission is of the order of eight seconds (Central Processing Unit time). The scheme now covers over 50 stations, including for the first time some in Scotland. The program is run daily throughout the year, but results are communicated to plant pathologists only during the part of the year when mildew is likely (mid April to end of July). However, the meteorological data are of relevance to agriculturists throughout the year so distribution to the regional meteorologists is continued. Because of this more general application, a section to extract daily minimum temperatures has been included in the program.

An automated 'apple scab' service was introduced in 1976. For several years before its introduction a manual scheme had been in operation in which infection periods were identified from hourly observations plotted on charts. Ten stations in the southern half of England were used. The Plant Pathology Laboratory at Harpenden was notified by telephone of infection periods as they occurred and these were confirmed by post. Plant pathologists at the Reading Regional Office of MAFF were informed by telephone of infection periods in their region.

The new scheme has enabled the number of observing stations used to be increased to 29. The distribution to the recipients has been improved, following the same method as that used in the barley mildew service. The computer program developed for the scheme uses several of the techniques in the barley mildew program. The principal difference lies in the cumulative aspect of the apple scab criteria in that the treatment of each observation depends on previous observations. The program is run each day throughout the critical time of year (1 March to 15 June). Data for each of the previous 24 hours are extracted, rainfall and relative humidity criteria examined and, when a high humidity period has ended, the time/temperature criteria are checked against a mathematical representation of the Mills time/temperature criteria. At the end of each day's run details of any continuing high humidity periods need to be stored for use on the following day.

Inclusion of other diseases

Schemes for two further diseases were introduced in 1976 and are on a trial basis. *Rhynchosporium* of barley and *septoria* of wheat are diseases for which experimental criteria have been suggested. Information on infection periods using these criteria is useful to plant pathologists currently conducting trials and may allow the criteria to be confirmed so that new routine services can be introduced. The criteria at present used for *rhynchosporium* require the same hourly data as those for apple scab. For *septoria*, rainfall totals are also needed and these are provided in the data output by the barley mildew program.

Conclusion

The automatic warning schemes have several advantages over the old methods. The repetitive process of data extraction is accomplished in seconds and the man-hours spent on the task are considerably reduced. Difficulties arising over backlogs of work after weekends and public holidays have been removed, and the load upon the limited staff of regional meteorologists has been reduced. The greater speed of the computerized scheme makes possible the incorporation of more observing stations thus giving a better service over the country. The resulting data are distributed earlier and to a greater number of interested recipients. Finally, the basic agrometeorological programs for extracting information from the synoptic data bank may apply to any agrometeorological situation where relationships with current meteorological data have been developed. Thus a continually improving service can be offered to the agricultural community.

The agrometeorological programs provide data on meteorological conditions consistent with the spread of plant diseases only if other conditions are satisfied in the field. The plant pathologists have to apply their own expertise and knowledge to the information which the Meteorological Office provides and to find appropriate ways of speedily conveying their warnings and advice to the farming and horticultural community.

Acknowledgements

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RAINFALL CRITERIA FOR URBAN DRAINAGE DESIGN

By J. F. KEERS

SUMMARY

An appraisal is made of those aspects of rainfall which are important for the economic design of urban storm water drainage systems. These include the mean rainfall intensity for specified durations, the average frequency of occurrence and regional variability of heavy local falls, the relationships between rainfall intensity and time (storm profiles) and between rainfall at a point and over an area. Also discussed are other aspects of rainfall which may be important as input to models of more advanced design including statistics describing the movement of extreme rainstorms, for example once-in-two-year storms, across the catchment.

INTRODUCTION

Urban drainage is concerned with the disposal of storm water, the removal of all waste water and the control of flood waters. Storm water, often referred to as surface water, is defined as the run-off of rainfall from both natural and artificial surfaces such as roads, roofs, etc. In many urban areas storm water and domestic sewage are discharged into the same pipe system, referred to as a combined system. There are also many examples of partially combined systems in the United Kingdom. In general, however, new sewerage schemes use separate systems for storm water and domestic sewage and then only the storm water sewers present a design problem because of the great variability of storm rainfall. In the United Kingdom the design of urban drainage schemes is commonly based on rainfall events (design rainfalls) with a frequency of between once a year and once in ten years but which may be up to once in 100 years in special circumstances.

The designer of storm water sewers is concerned with two types of rainfall: average rainfalls over long periods and heavy rainfalls of short duration, usually less than two hours. The former are required for estimating annual pumping costs, and the latter for determining the size of sewers, pumps, etc. The good daily rain-gauge network in the United Kingdom, approximately 3000 stations in the year 1900 and 7000 stations today, has enabled meteorologists to determine for any location or catchment area (i) monthly, seasonal and annual rainfall averages, and (ii) the geographical variation of daily or longer-period rainfall totals with any specified frequency of occurrence.

The network of continuously recording rain-gauges is much less dense than the daily rain-gauge network and until recently the best statistics of short-duration rainfall, i.e. less than a few hours, were those derived by Bilham (1936) and modified by Holland (1964). Bilham used 10 years of data (1925 to 1934) from only 12 recording rain-gauge stations widely distributed throughout England and Wales to derive a formula for estimating an average frequency of intense short-duration rainfall (up to two hours duration). Holland (1964) modified Bilham's formula for rainfalls with intensity above 32 mm/h. Holland (1967) also investigated plots of rainfall intensity against time, hereinafter referred to as storm profiles, and the relationship between point and areal rainfall for areas up to 20 km^2 in size using data from a close network, with an inter-gauge spacing of approximately 1 kilometre, of recording rain-gauges near Cardington in Bedfordshire.

In the mid 1960s the Road Research Laboratory (RRL)—now the Transport

and Road Research Laboratory (TRRL)—developed a computer package based on *Road Note* No. 35 (1963) for assisting with the design of drainage systems, including sewer systems. The RRL method used the results of Bilham and Holland for determining design rainfalls. Neither Bilham nor Holland considered the geographical variation of frequencies of short-duration rainfall. Moreover, neither author overcame the restrictions imposed by the shortage of long-period records from recording rain-gauges or the problem of the great variability in time of extreme rainfall in a two-hour storm.

In order to overcome the limitations of the results of Bilham and Holland, an intensive investigation of rainfalls of all durations has been made using all available rainfall records, reports of thunder, observations of precipitable water, etc., for stations in the British Isles. This work was carried out under the direction of A. F. Jenkinson of the Meteorological Office during the years 1971 to 1974 and culminated in the publication of the *Flood Studies Report* (Vol. 2—Meteorological Studies) in March 1975. Vol. 2 of the *Report* quantifies the significant geographical variation in the rainfalls of any specified return period and duration up to one month. Also the availability of relatively long-period rainfall records from a selection of stations means that estimates of the rainfall of longer return periods derived using the *Flood Studies Report* are more reliable than previous methods of estimation. The *Flood Studies Report* also enables the storm profile to be specified for design purposes and this will be discussed in a later section.

Mean rainfall intensity for design purposes

One of the most common storm sewer design methods is known as the Rational or Lloyd-Davies (1906) Method. This method relates the peak flow in the sewer, Q, to the size of drainage area, A, a surface impermeability factor, p, and the mean rainfall intensity, $\bar{R}$ (the latter for a specified duration and average frequency of occurrence) as follows:

$$Q = C_1 A p \bar{R}, \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where the constant C_1 depends on the units employed.

For a particular urban catchment the drainage area may be taken as constant and if the impermeability factor is also fixed, i.e. its variability is neglected, Equation (1) reduces to

$$Q = C_2 \bar{R}, \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where C_2 is a known constant.

Before the Road Research Laboratory introduced their computer package for drainage design in the mid 1960s it was common practice to use an equation of type (1) or (2), and even today *Road Note* No. 35 (1963) (1976 revision in the press) recommends that such an equation should be used when the largest sewer does not exceed 2 ft ($\approx$0·6 m) in diameter, since the simplifications involved are not significant in terms of selected pipe diameter. From Equation (2) the fundamental importance of the mean rainfall intensity over short durations is obvious and many researchers have devised equations for determining the rainfall in the United Kingdom for a range of durations and return periods (Bilham, 1936; Maclean, 1945; Holland, 1964). However, the *Flood Studies Report* (1975) undoubtedly presents the most reliable method so far devised for determining the design rainfall for any location in the United Kingdom; an example of the

sort of rainfall data which can be derived is given in Table I. In Table I an event with an average frequency of occurrence of once-in-*N*-years is referred to as an event with a return period of *N* years.

TABLE I—RATES OF RAINFALL AT BALA IN NORTH WALES FOR SPECIFIED DURATIONS AND RETURN PERIODS

	Return period (years)						
	1	2	5	10	20	50	100
Duration (minutes)				*mm/h*			
2	50	61	78	89	102	120	136
5	38	47	61	71	81	96	109
10	29	35	47	54	63	75	87
15	24	29	39	45	53	64	74
30	17	21	27	32	38	46	54
60	11·8	14	19	22	26	32	37
90	9·5	11·4	15	17	21	25	30
120	8·2	9·7	12·4	15	17	21	25
(hours)							
4	5·6	6·6	8·2	10·3	11·3	13·8	16·0
6	4·5	5·3	6·4	7·5	8·7	10·6	12·2
12	3·1	3·6	4·2	4·9	5·6	6·7	7·6

TIME OF CONCENTRATION

It has been common practice to design a storm sewer by assuming that the *N*-year peak flow in the sewer is directly attributed to the *N*-year rainfall. The mean rainfall of any specified return period decreases markedly with increasing duration and so it is very important to specify the optimum duration of rainfall for design. When Equation (1) or (2) is used the optimum duration is the time taken for the maximum flow in a sewer to reach the design point* from the remotest part of the drainage area. This duration is called the time of concentration and is made up of the time of entry, i.e. the time for rain water to run over roof and road surfaces etc. before reaching the sewer, plus the time of flow through the sewers to the point at which the discharge is to be calculated. In general the larger the drainage area the longer the time of concentration, but other contributory factors include the size and gradient (slope) of the sewers and the type of land and its use. The time for rain water to run off an unpaved surface, such as school playing fields, is greater than the time required to run off a steeply sloping roof and through a short length of drain before arriving at a sewer. Formulae for computing the time of peak run-off and time of flow in the sewers were developed more than 50 years ago but as with rainfall the variability with time presents problems. Typically the time of concentration varies between a few minutes for a small residential estate to a few hours for a medium-sized town.

STORM PROFILES

Storm rainfall rarely falls at a uniform rate. The profile of rainfall intensity versus time, as in Figure 1, is commonly referred to as a storm profile. For drainage design purposes the storm profile is important because for a specified duration and total rainfall the storm with the greatest peak intensity, i.e. the sharpest profile, will often result in the greatest peak flow in the sewer. Also the

* Design point: point of outfall of all upstream sewers for the particular piece of pipe being designed.

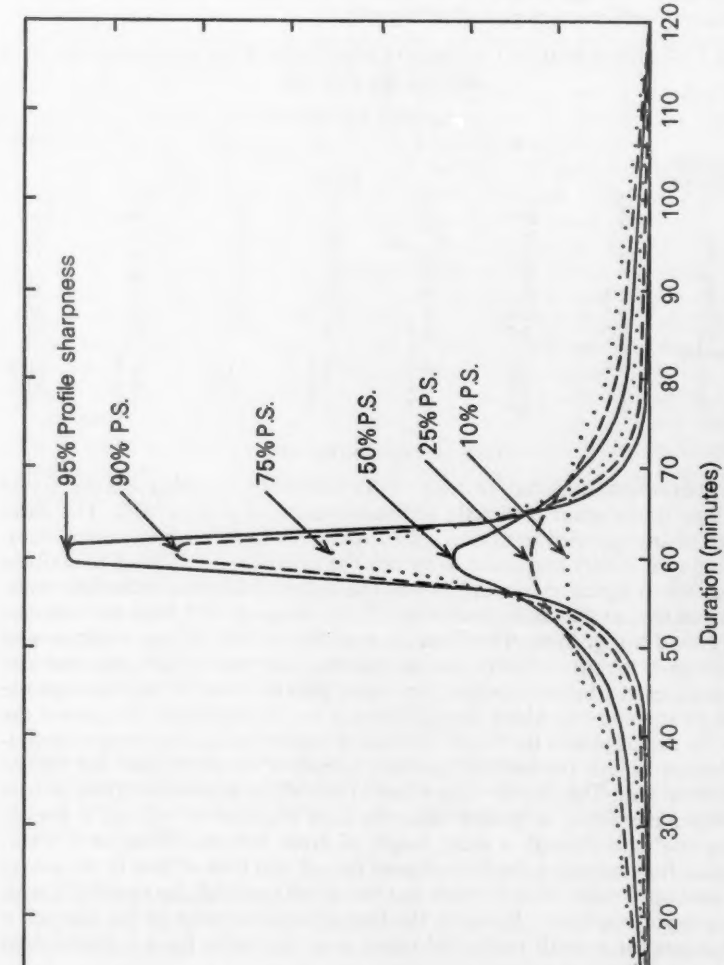

FIGURE 1—RANGE OF STORM PROFILES
(return period of one year)

variation of flow with time, i.e. the hydrograph, can only be investigated if the rainfall input is also allowed to vary in time as occurs in nature.

For a given storm duration and total rainfall there is an infinite variety of storm profiles. The variation is caused by the different rainfall types; for example, very sharp storm profiles of short duration (less than two hours) are usually associated with convective storm rainfall and flatter profiles with more continuous and less intense rainfall processes such as warm-front rain. The speed of movement of the rainfall system across the point or area and the local development and decay of rainfall intensity contribute to the shape of the storm profile. The research carried out in the Meteorological Office on the subject of storm profiles (*Flood Studies Report* (1975)) included a percentile analysis of profile sharpness. The results of this analysis apply to design storm profiles of any specified duration. The technique used by the Flood Studies research team ensures that all the storm profiles derived for design purposes are symmetrical about the mid point of the specified storm duration. A 90 per cent profile is one which is not exceeded in terms of sharpness of the storm profile shape on 90 per cent of occasions, where a numerical measure of sharpness is given by the ratio of maximum rainfall rate to mean rate over the whole duration of the storm. The 50 per cent profile is the median profile. Figure 1 shows some storm profiles at a given location for a fixed duration and return period. Figure 2 presents a range of 50 per cent profiles for the same location, and illustrates the fact that the shape of the profile is a function of the duration.

A design engineer is faced with some difficult problems if he wishes to use the results referring to the various shapes of the storm profile, for example how sharp should the storm profile be and what storm duration should be used. In practice an engineer generally opts for a simplified design technique. For example the RRL *Road Note* No. 35 (1963) storm sewer design technique uses the same storm profile for all locations, and although the rainfall changes with return period the shape and duration of the profile does not change. However, this approach assumes that variation of storm profile sharpness and storm duration are not important, which may not always be true.

A weakness of the storm profiles described in *Road Note* No. 35 (1963) is that the total rainfall in the two-hour period is varied according to the return period required, but no consideration is given to the probability of such a sharp storm profile occurring. Also there may be occasions when the optimum storm duration may be greater or less than two hours. These storm profiles simplify rainfall input since their construction assumes that one storm profile of specified return period is adequate for all pipe systems with a time of concentration of approximately two hours or less. This assumption stems from the N-year 10 minute rainfall being 'nested' in the N-year 15 minute rainfall and this in turn being nested in the N-year 30 minute rainfall, and so on up to 120 minutes.

The *Flood Studies Report* (1975) permits a design storm profile to be constructed to any predetermined specification and if the specification is not certain a variety of design storms can be constructed, all for a given return period. The best storm for a particular design purpose can then be determined by experiment.

The Meteorological Office and the Transport and Road Research Laboratory carried out a series of experiments with differently shaped storm profiles and concluded that there is a relationship between storm duration and the sharpness of the storm profile. In effect if the required once-in-N-year rainfall is distributed in time according to the median summer storm profile (50 per cent) then

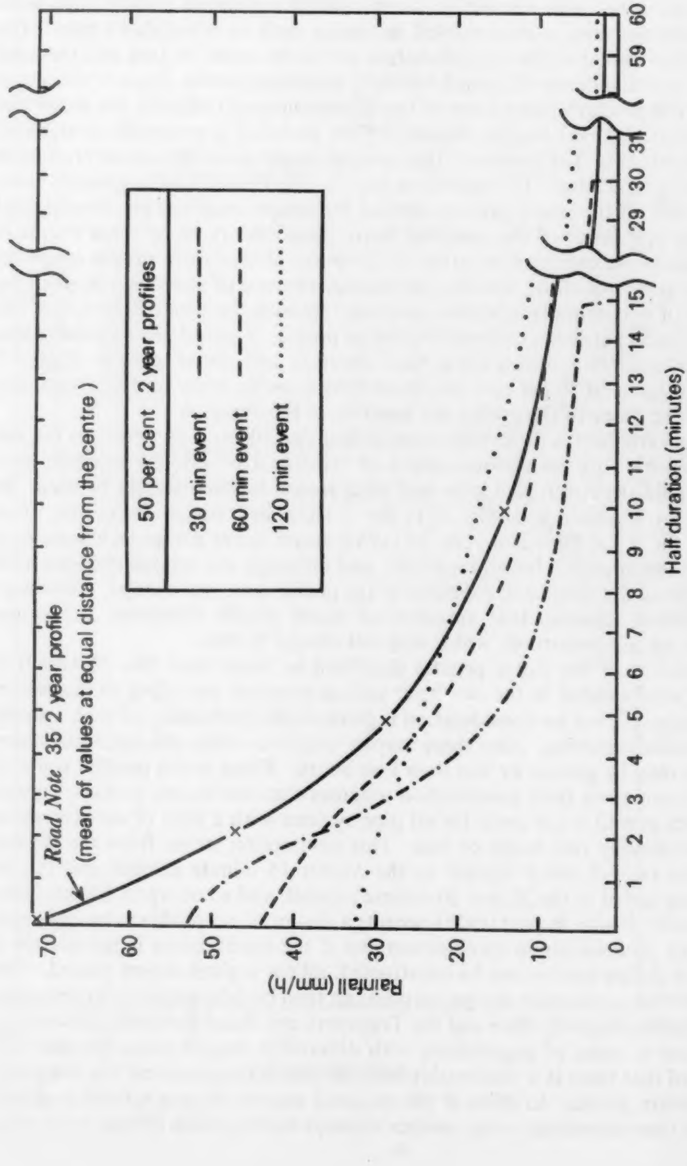

FIGURE 2—COMPARISON OF STORM PROFILES
(return period of two years)

the optimum (resulting in greatest peak flow) storm duration is between two and three times the time of concentration; for example the 60 minute storm should be used for a drainage scheme with time of concentration 20 to 30 minutes but the pipes lying far upstream should be designed using a shorter-duration storm or mean rainfall intensities applied by using the Rational Method. Figure 3 illustrates the application of this technique to a large urban surface water sewer system. The Institute of Hydrology (*Flood Studies Report*, Vol. 1 (1975)) also recommends a particular shape of storm profile (75 per cent winter profile) for river catchment studies with the storm duration determined from catchment characteristics and the total depth of rainfall determined by the specified return period.

Point to area rainfall relationships

The depth–duration frequency relationships for extreme rainfalls (twice-a-year and over) discussed earlier in this paper all refer to point rainfalls, i.e. to rainfall at a specific location, since they all derive from rain-gauge measurements. Invariably the design engineer requires information on areal rainfall rather than on point rainfall where typically the area may be an electricity generating station, an urban area, or a large river catchment.

Consider a particular river catchment with several rain-gauges suitably located to obtain a good estimate of the mean catchment rainfall. Some rainfall events will give little or no rain at a particular rain-gauge location even though the mean catchment rainfall is very large. Other rainfall occasions may result in an extremely high rainfall at the same rain-gauge location when the mean catchment rainfall is relatively low. However, for extreme rainfall events, for example once-a-year or rarer events, the N-year point rainfalls meaned over all rain-gauge locations will always be greater than or equal to the N-year catchment rainfall. This is because extreme rainfall events often affect only a limited part of a catchment and during the course of a year there are enough extreme rainfall events affecting different parts of the catchment to result in each point location's experiencing at least one rainfall that is greater than the greatest single rainfall event averaged over the whole catchment. This simplified explanation may not apply to a catchment with very varied rainfall characteristics, however, because in this case the N-year mean catchment rainfall may be greater than the N-year rainfall for some point locations in the generally drier part of the catchment; the practical application of the areal reduction factor (ARF) takes this into consideration.

The factor to be applied to the mean of the N-year point rainfalls to reduce it to the N-year catchment rainfall is commonly called an areal reduction factor (ARF). The spatial variability of rainfall is such that the ARF approaches unity as the size of area decreases. Also the spatial scale of storm rainfall generally increases with increasing duration, therefore for design storms the ARF approaches unity as the rainfall duration increases. Table II presents the relationship between the ARF, size of area and rainfall duration, as given in the *Flood Studies Report* (1975).

Every rainfall event affects an area rather than a point and the area–depth relationship is different in every case. The values of ARF in Table II present a statistical relationship between N-year point rainfalls and N-year areal rainfall events, where the geographical differences are accounted for by the differences in point rainfall values. Thus depth–duration-frequency statistics for areal rain-

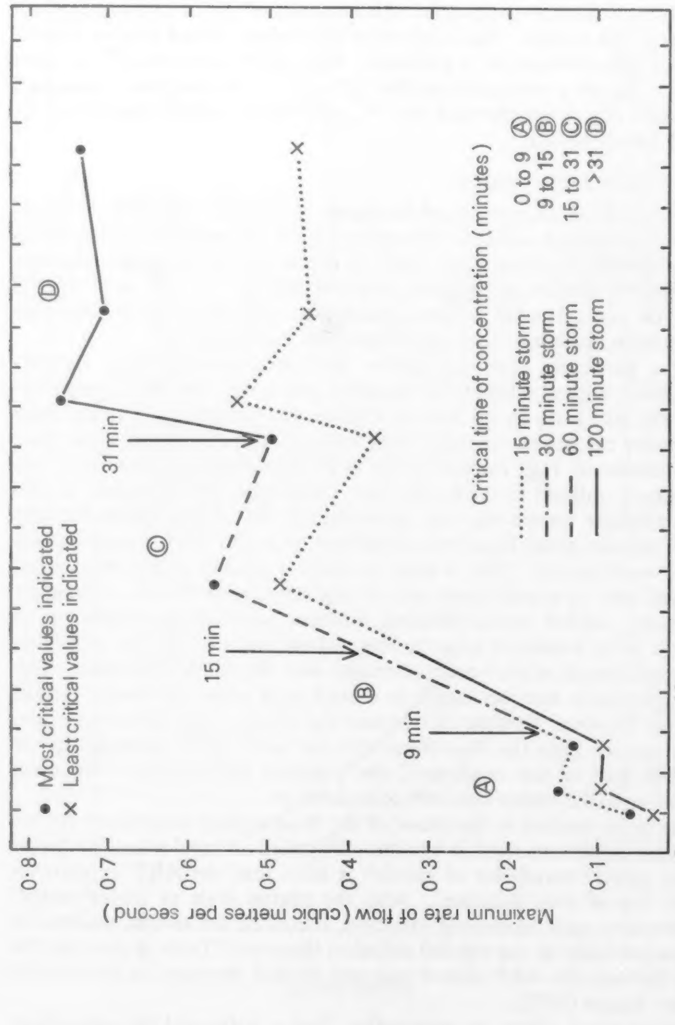

FIGURE 3—VARIATION OF FLOW RATES WITH TIME OF CONCENTRATION AND DURATION OF STORM EVENT

fall can be derived from the comprehensive statistics of point rainfall. An alternative approach using only areal rainfall factors to investigate areal rainfall statistics is not justified in view of the relatively limited data on extreme areal rainfall events compared with point rainfall measurements in many parts of the United Kingdom. Also the spatial variability of rainfall is such that in many instances areal rainfall cannot be adequately measured from the existing network of rain-gauges.

TABLE II—AREA REDUCTION FACTOR

	Area (km²)						
	1	5	10	30	100	300	1000
Duration (minutes)							
5	0·90	0·82	0·76	0·65	0·51	0·38	0·28
10	0·93	0·87	0·83	0·73	0·59	0·47	0·32
15	0·94	0·89	0·85	0·77	0·64	0·53	0·39
30	0·95	0·91	0·89	0·82	0·72	0·62	0·51
60	0·96	0·93	0·91	0·86	0·79	0·71	0·62
(hours)							
2	0·97	0·95	0·93	0·90	0·84	0·79	0·73
3	0·97	0·96	0·94	0·91	0·87	0·83	0·78
6	0·98	0·97	0·96	0·93	0·90	0·87	0·83
24	0·99	0·98	0·97	0·96	0·94	0·92	0·89

STORM MOVEMENT AND OTHER RAINFALL FACTORS

The models used for designing urban storm water sewer systems in the United Kingdom do not specifically take account of the dynamic effects associated with storms moving across the drainage catchment. The effect of storm movement is to complicate the sequence, and therefore the magnitude, of the peak flows in the various branches of the sewer system. The peak flows may be significantly increased if the storm rainfall movement is of comparable speed and direction to the flow in the sewer system. Speed of storm rainfall movement often exceeds 10 m/s, which reduces the possibility of movement significantly affecting the peak flow in the sewer, since the latter is generally less than 3 m/s. However, if there are preferred directions of storm rainfall movement then this may be important for some drainage purposes. Other rainfall factors such as shape and orientation of the rainfall area are relatively unimportant factors for urban drainage design criteria.

Many towns and cities in the United Kingdom have large recreational areas, and many have flood plains adjoining rivers and streams, wherein antecedent rainfall may be important for drainage design purposes through its effect on soil moisture and hence on rainfall run-off characteristics. The latter is a subject which is now being investigated at several establishments including the Institute of Hydrology, Bristol University and Imperial College, using statistical-empirical models, analytical models and physical models. Given a design rainfall, the surface run-off must be determined and then the actual flows in the sewer must be estimated. The latter is a problem of hydraulics and is being studied at the Hydraulics Research Station, Wallingford.

CONCLUSION

The rainfall depth, for a specified frequency and duration (approximately the time of concentration of the sewer system) is the most important single rainfall

factor for design purposes. The location with respect to preferred areas of heavy short-duration rainfall is also important. Storm profiles represent the variation of rainfall in time and obviously this variability is significant since storm water sewers are designed to cope with peak flows rather than mean flows. The spatial variation of rainfall over a drainage area is dealt with statistically by applying an areal reduction factor.

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REVIEWS

The weather almanac (first edition), edited by J. A. Ruffner and F. E. Blair. 225 mm × 150 mm, pp. viii + 578, Gale Research Company, Book Tower, Detroit, Michigan, 1974. Price $17·50.

The major part of this Almanac describes the weather and climate of the United States of America. The averages and extremes of temperature and the averages of precipitation and sunshine are presented in a series of charts for the country as a whole and these are followed by sections describing the types of severe weather affecting various regions, hurricanes, tornadoes, winter storms, heat waves etc. Over one-half of the volume is devoted to detailed statistics for over 100 cities throughout the 50 States. Accompanying texts successfully highlight the principal features of the topographical situation and local climate of each city. The Almanac should appeal to the weather-conscious citizen who wishes to know the average conditions to be expected during a business journey or when on vacation. A comparatively short section entitled Round-the-World Weather contains basic temperature and rainfall statistics for some 500 locations outside the USA.

P. G. F. CATON

British weather disasters, by Ingrid Holford. 250 mm × 170 mm, pp. 127, *illus.,* David and Charles, Brunel House, Newton Abbot, Devon, 1976. Price £4·75.

This book is an attempt to gather together non-technical descriptions of some of the disasters resulting from weather action which have occurred in Britain over the last three centuries. The criteria for the selection of the events described are not stated or even implied, since although loss of life occurred in most of the cases discussed, one or two resulted merely in damage, albeit severe, to property or structures. Of the 39 events described, 30 are from the present century and 23 occurred after 1950, but this apparent bias towards more recent events is perhaps understandable in a book intended for the popular market. Press reports have been used extensively as the basis for the descriptions of the events from recent decades and many spectacular photographs of devastation accompany the text.

The earliest case described is one of lightning damage to the church at Widecombe-in-the-Moor, Devon, on 21 October 1638, and the latest one of local flooding at Surbiton in July 1973. Other notable rainfall flooding events described include the two events in southern England in 1968, the Lynmouth catastrophe of 1952 and the Norwich flood of 1912. The storm surge floods of 1928 and 1953 are discussed, as are the effects of the 1947 snowmelt floods. Occasions of severe wind damage in urban areas include the Sheffield gales of 1962 and the central Scotland gales of 1968. In most cases, the author presents a simple description of the synoptic development prior to the event, and then describes the damage caused and the effects on the unfortunate people involved.

A few errors were noted in the book. The date of the Tay Bridge collapse is consistently given as 1897, instead of 1879, and the diagram purporting to show calculated streamlines over the Pennines at the time of the Sheffield gales of 16 February 1962 relates, in fact, to 12 February.

The scientific content of this book will satisfy neither the professional meteorologist, concerned with understanding and possibly predicting extremes of weather, nor the professional engineer, concerned with establishing a rational and economic design standard. However, the human implications of weather disasters should be borne constantly in mind by both. Unless one has been personally involved with events of the kind described, the memory of such events soon fades, and so perhaps an important function of a book such as this is to act as a reminder to meteorologists, hydrologists and structural engineers that disasters continue to occur in Britain despite improvements in their technical skills.

J. S. HOPKINS

Note. That the wrong streamline diagram for the Sheffield gale was printed in *British Weather Disasters* was to a considerable extent the fault of the Meteorological Office who supplied the wrong original drawing of the diagram from *Geophysical Memoirs* Mo. 108. This drawing had been incorrectly annotated and the mistake was not discovered until the book was ready for publication.

(Editor)

The physics of atmospheric ozone, A. Kh. Khrgian, 245 mm × 175 mm, pp. v + 262, *illus.,* (translated from Russian by Israel Program for Scientific Translations, Jerusalem), John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1975. Price £13·25.

The book is a translation of a Russian original published in 1973. It sets out to give an historical review of all branches of research on ozone in the atmosphere,

with the exception of its role in the ionosphere and in polluted urban atmospheres. The translation reads easily, though at least in one place transliteration into Cyrillic script and back again has transformed Århus into Orkhus. The technical description of instruments clearly presents problems for a translator, and it is not clear whether it was during translation into Russian or back into English that 'phosphor' became 'phosphorus' (p. 48) and 'sputtering' became 'spraying'.

There is little doubt that the Russian original provided a useful background for workers entering the sphere of ozone research after the upsurge of interest which followed the assertion in 1971 that oxides of nitrogen in the exhaust of stratospheric aircraft could damage the ozone layer. There is, however, no mention of this in the text and the only extension of the Chapman oxygen-only photochemical model to find a place is the inclusion of odd hydrogen species OH and HO_3. The latest of the 436 references is dated 1970.

While the book is an historical review, it has a typically eastern lack of historical perspective. All authors are equally in the foreground of the picture. Thus one is left at the end of Chapter V with the impression that the only significant measurements of ozone in the troposphere are those of Kay in 1952–53 and Britaev in 1960–61, quite ignoring the wealth of data available from the lower portions of stratospheric ozonesonde ascents. This particular instance is due in part to the author's distrust of ozonesondes in the troposphere, which he states without justification in Chapter VIII (p. 147). Elsewhere the tendency is to accept all authors and data uncritically.

The units used in ozone research have varied over the years, depending on the starting point of the authors' interests, and the inclusion of a section on units in Chapter III is very useful. The author points out that the reduced thickness of ozone per kilometre of atmosphere (expressed in 10^{-3} cm/km) is in fact a measure of ozone (partial) density, and gives the equivalent in μg m^{-3}. He then, astonishingly, says it is a volume mixing ratio of 10^{-8}, and is abbreviated pp h m.

Notwithstanding the probable usefulness of the Russian original, this translation is now little more than a comprehensive review of ozone literature prior to 1971, and as such is of only limited use to anyone engaged in ozone studies in the late 1970s.

E. L. SIMMONS

CORRECTION

Meteorological Magazine, March 1977, p. 91. After end of 'The Meteorological Magazine 1866–1977' article, add

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	1938	*Met Mag,* **73**, pp. 165–168.

OBITUARIES

It is with regret that we have to record the death on 9 December 1976 of Mr R. R. Webb, Assistant Scientific Officer, Port Meteorological Office, Southampton, and on 27 January 1977 of Miss J. C. Perfect, Higher Scientific Officer, Met O 11.

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